

# Quadrupole Stark Effect in Superfluid

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## Abstract

The roton energy depends on applied electric field gradient due to its quadrupole moment. This may explain absorption line splitting recently observed experimentally.

Line splitting in the conventional Stark effect is explained by the interaction of applied electric field and intrinsic dipole moment of an atom. Rotons have no dipole moment (nor they have any charge). The leading term in the energy expansion of a neutral system with zero dipole moment is given by [1]

$$U = \frac{D_{\alpha\beta}}{6} \frac{\partial^2 \phi_0}{\partial x_\alpha \partial x_\beta}. \quad (1)$$

Here  $D_{\alpha\beta}$  is the electric quadrupole moment of the system and  $\phi_0$  is the potential of external field.

The quadrupole moment of a roton was estimated earlier [2] as

$$D_{\alpha\beta} \sim \frac{Ze\Delta}{24M^{1/3}c^2\rho^{2/3}} \left( \frac{p_\alpha p_\beta}{p^2} - \frac{\delta_{\alpha\beta}}{3} \right), \quad (2)$$

where  $Z = 2$  for helium,  $e$  is the elementary charge,  $\mathbf{p}$  and  $\Delta$  are the roton momentum and energy,  $M$  is the atom mass,  $c$  is the sound velocity, and  $\rho$  is the fluid density.

Rotons are commonly imagined as microscopic vortex loops (hence the name). It is interesting to note that macroscopic loops are also expected to possess electric quadrupole moment [3].

The frequency shift due to quadrupole interaction can be estimated as:

$$\Delta f = \frac{U}{2\pi\hbar} \sim \frac{e\Delta}{144\pi\hbar M^{1/3}c^2\rho^{2/3}l} E, \quad (3)$$

where  $l$  is some inhomogeneity length scale and  $E$  is the electric field. In the experiment [4]  $l \sim 1$  mm. Thus

$$\frac{\Delta f}{E} \sim 2 \frac{\text{Hz}}{\text{V/cm}}. \quad (4)$$

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This is close enough to the experimentally measured value of 42.65 Hz cm/V.

To confirm the quadrupole character of observed effect we propose an experiment with a different geometry, so that the influence of the field *gradient* on the line splitting can be found.

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## References

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